REPORT DOCUMENTATION PAGE

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Final Report: Imaging System for Extending Evanescent-Wave Particle Velocimetry to Wall Turbulence

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5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
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6. AUTHORS
Minami Yoda

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

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61493-EG-RIP.1

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13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT
This final report describes the two major pieces of equipment acquired under this DURIP grant, namely a pair of lasers and a high-speed intensified digital camera system. The equipment will be used to determine whether it is feasible to use the new evanescent wave?based particle?tracking velocimetry (PTV) technique to visualize a “slice” of the viscous sublayer in wall turbulence parallel to the wall in fully?developed turbulent channel flow. Understanding the characteristics of wall(?bounded) turbulence, especially in the viscous sublayer, i.e., the thin flow region next to the wall where viscous effects dominate, is the key to understanding the drag and lift forces

15. SUBJECT TERMS
Wall turbulence; evanescent-wave imaging

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Minami Yoda
UU	UU	UU	UU		19b. TELEPHONE NUMBER 404-894-6838

Report Title

Final Report: Imaging System for Extending Evanescent-Wave Particle Velocimetry to Wall Turbulence

ABSTRACT

This final report describes the two major pieces of equipment acquired under this DURIP grant, namely a pair of lasers and a high-speed intensified digital camera system. The equipment will be used to determine whether it is feasible to use the new evanescent wave?based particle?tracking velocimetry (PTV) technique to visualize a "slice" of the viscous sublayer in wall turbulence parallel to the wall in fully? developed turbulent channel flow. Understanding the characteristics of wall(?bounded) turbulence, especially in the viscous sublayer, i.e., the thin flow region next to the wall where viscous effects dominate, is the key to understanding the drag and lift forces acting upon solid surfaces moving through a fluid.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Dr. Yoda became a Fellow of the American Physical Society (nominated by the Division of Fluid Dynamics) in November 2012.

Graduate Students

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Post Doctorates

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Minami Yoda	0.00	
FTE Equivalent:	**0.00**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 0.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME
Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Understanding the characteristics of wall(-bounded) turbulence, especially in the thin flow region next to the wall where viscous effects dominate, is the key to understanding the drag and lift forces acting upon solid surfaces moving through air or water, such as aircraft wings, helicopter blades, and ship hulls. Yet recent studies suggest that the flow in the inner region (i.e., the viscous sublayer and buffer layer) actually depends upon the specific type of wall turbulence, calling into question the classic "universal" scaling of wall turbulence.

We will use the high-speed lasers and camera system purchased with this DURIP grant (see attached table for specifics) in a feasibility study, supported by a STIR grant (66195EGII), to determine if evanescent wave-based particle-tracking velocimetry (PTV) can be used to visualize a "slice" (with dimensions exceeding 500 wall units) of the viscous sublayer parallel to, and within ~1.5 wall units of, the wall in fully?developed turbulent flow through a 1 mm square "minichannel" under conditions where a wall unit is about 1 micrometer at a spatial resolution, based on the particle size, of 0.5 wall units. This equipment will therefore be used by the postdoctoral researcher working on this grant, who is at present waiting for approval of his Optional Practical Training by US Citizenship and Immigration Services.

Note that no personnel were supported by this grant because it is solely for equipment.

Technology Transfer

NA

Scientific Progress

Imaging System for Extending Evanescent-Wave Particle Velocimetry to Wall Turbulence
61493EGRIP
Minami Yoda, *Georgia Institute of Technology*

Understanding the characteristics of wall(-bounded) turbulence—the thin flow region next to the wall where viscous effects dominate—is the key to understanding the drag and lift forces acting upon solid surfaces moving through air or water, such as aircraft wings, helicopter blades, and ship hulls. Yet recent studies suggest that the flow in the inner region (*i.e.*, the viscous sublayer and buffer layer) actually depends upon the specific type of wall turbulence, calling into question the classic "universal" scaling of wall turbulence.

We will use the high-speed lasers and camera system purchased with our DURIP grant (detailed in the attached table) in a feasibility study, supported by a STIR grant (66195EGII) to determine if the new evanescent wave-based particle-tracking velocimetry (PTV) technique can be used to visualize a "slice" (with dimensions exceeding 500 wall units) of the viscous sublayer parallel to (and within ~1.5 wall units of) the wall in fully-developed turbulent flow through a 1 mm square "minichannel" under conditions where a wall unit is about 1 μm at a spatial resolution, based on the particle size, of 0.5 wall units.

This equipment will be used by a postdoctoral researcher who is currently waiting for approval of his Optional Practical Training by the US Citizenship and Immigration Service. Since this grant is only for equipment, no support for any personnel, including students, was provided by these funds.

Project # **2506H00**
Contract No. **W911NF-12-1-0343**

Date Acquired	Description	PO #	Cost	Charged to Award
6/13/2014	Digital High-Speed Intensified Camera System	2500170157	64,110.00	64,110.00
	(Princeton Instruments PI-MAX4)			
8/27/2014	Two Q-switched frequency-doubled Nd:YAG Laser Systems	2500189110	36,585.00	36,585.00
	(Spectra-Physics Explorer 532-2Y)			
			100,695.00	100,695.00